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ERCB

Risk to Water Wells of Pathogens in Drilling Fluids

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Energy Resources Conservation Board

ENERGY RESOURCES CONSERVATION BOARD
Report 2009-C: Risk to Water Wells of Pathogens in Drilling Fluids

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Executive Summary

The Energy Resources Conservation Board (ERCB) is aware of the public concern regarding the presence of pathogenic microorganisms in surface waters used in drilling fluids and their potential impact on groundwater and/or water wells. The most common sources of water used in drilling fluids include dugouts, sloughs, small creeks, and beaver dams. As a result of public concerns, the ERCB retained the third-party expertise of Dr. Abimbola Abiola, microbiologist from Olds College, and Dr. Cathryn Ryan, hydrogeologist from the University of Calgary, to prepare a report on the abundance of pathogens in surface waters and evaluate whether pathogens in surface waters that are used in drilling fluids in Alberta have the ability to survive in or be transported through a groundwater system and to report their findings. The report is a professional opinion based on an extensive review of literature and professional experience and is written for a general public audience.

A summary of the key findings presented in their report is as follows:

1) The subsurface presents a hostile environment to surface water pathogens given its lower temperatures, lower oxygen levels, and fewer nutrients.

2) Pathogens can be introduced into surface waters through animal wastes, sewage, and industrial or agricultural effluents.

3) The types of pathogens typically found in Alberta surface waters are unlikely to survive the salt levels found in nontoxic drilling fluids.

4) Pathogen transport into the subsurface is unlikely, even over short distances, due to the typically low infiltration distance of drilling fluids from the wellbore.

1 Risk to Well Water of Pathogens in Drilling Fluids

1.1 What are pathogens?

Pathogens are disease-causing living organisms. Most pathogens are microscopic, and are therefore too small to see with unaided eyes. They are a small subset of microorganisms that have the capability to make people sick when they are ingested at a high enough dose; they include bacteria, viruses, fungi, and protozoa. The word "pathogenic" means disease causing.

Viruses are the smallest of the microorganisms. In terms of size, a 1 millimetre (mm) pinhead could have up to 50 million viruses arranged head to tail across its diameter. Viruses on their own are not true living cells. Microbiologists consider viruses as infectious agents that require living cells for their reproduction. In fact, because of their small size and since they cannot reproduce and grow on their own without a living host, they were not recognized as living organisms for a long time. Populations of viruses that are pathogenic to humans do not increase in the soil, since human hosts are required. The types of viruses whose populations increase in soils are those that use soil bacteria for growth, and they may actually be positive in controlling bacterial pathogen populations in soils. Viruses are not easily destroyed by disinfection and filtration in porous media due to their small size. It has been demonstrated that biofilms created by some microorganisms on porous media in subsurface environments are able to trap viruses, and some protozoa also graze on them. Examples of viruses are Rotavirus, Hepatitis A, and Picornavirus (influenza virus). Unfortunately, virus analyses are relatively difficult, so most of the research has been conducted on bacteria.

Bacteria include pathogenic organisms and microorganisms such as *Escherichia coli* (*E. coli*) (hamburger disease and diarrhea), *Pseudomonas aeruginosa* (ear infections), *Staphylococcus aureus* (food poisoning and skin infections, such as boils), *Shigella* spp. (dysentery), *Salmonella* spp. (food poisoning and typhoid fever), and *Campylobacter* spp. (diarrhea, cramping, and abdominal pains). They exist as complete individual units capable of growing on their own outside of a host as long as they have appropriate conditions (e.g., the right moisture, temperature, nutrients). They grow by doubling, which means that one cell grows and divides up into two identical cells. Bacteria are on average 100 times as big as most viruses, which means that about 500 000 bacteria cells could line up head to tail across the diameter of a pinhead. Unlike viruses, they are very sensitive to heat treatment, disinfection, desiccation (drying) and lack of nutrients.

Pathogenic protozoa exist as single cells, and they generally require spending at least part of their life-cycle in a host, such as humans or other animals. They are moderately resistant to disinfection but are easily removed from water in the soil by filtration because of their larger size. Protozoa are on average five times as large as an average bacterium, which means that about 100 000 cells could fit across the diameter of a pinhead. Examples of pathogenic protozoa are *Giardia* spp. (beaver fever), *Entamoeba histolytica* (amoebic dysentery), and *Cryptosporidium* spp. (cryptosporidiosis).

1.2 Are all bacteria and other microorganisms pathogenic?

No. In fact, over 99 per cent of microorganisms found in the environment are either beneficial or have no negative impacts on humans. They are present everywhere: our bodies, intestinal tracts, soil, water, and the air that we breathe all contain different types of microorganisms. Many microorganisms are involved in the production of food and are also responsible for the growth of healthy plants and animals. Without these microorganisms, our wastes would not be broken down, agricultural production would be nonexistent, and many of the present-day medicines would not exist. Nature is not sterile, but consists of myriad seen and unseen

organisms in harmony. Pathogens are also present in the environment, but often do not cause diseases unless the ecological balance of the environment has been shifted.

1.3 How can we detect pathogens in water?

Though it is possible to detect most pathogens in a water sample, it is not practical because the identification process typically takes a long time and could be prohibitive in terms of cost. Additionally, no single method can detect all pathogenic microorganisms in a water sample. Since many of the procedures used involve the cultivation of the pathogenic microorganisms themselves, microbiologists often test for "indicator organisms." This reduces the possibility of environmental contamination and exposure of people to potentially harmful doses of pathogens. Common indicator organisms used to test for water potability include *E. coli* and fecal coliforms.

1.4 What are indicator organisms?

Indicator organisms, as the name implies, are used as a measure of the likelihood of the presence of pathogenic microorganisms in water. We analyze for them, rather than the pathogens themselves, because the indicator organisms are typically present at much higher concentrations (and therefore can be found using reasonably easy analytical methods). Their presence in the water indicates that the water source has recently been exposed to materials that may contain pathogens, for example fecal wastes. Most pathogenic organisms are spread through fecal contamination, exchange of body fluids, and physical contact between individuals. Some diseases are also spread to humans from nonhuman sources, such as livestock. Indicator organisms are therefore surrogate organisms whose presence in the environment signifies an increased risk of exposure to a pathogen. An ideal indicator organism should be applicable to different types of pollution sources and be easy and fast to detect, and its numbers observed in the sample should be proportional to the risk posed by the level of pollution.

1.5 What are the commonly used indicator organisms of water pollution?

There is no one perfect indicator organism for monitoring the pollution of water. The most commonly used indicator organisms or groups of organisms are types of coliform bacteria, including fecal coliforms and *E. coli*. Coliforms are a group of organisms commonly found in the intestines of humans and other warm-blooded animals, as well as birds and some reptiles. Total coliforms include all members of the group, some of which are known to exist in uncontaminated, even pristine, environments. They include *E. coli*, which could be pathogenic, and other organisms that are found in uncontaminated environments, such as *Enterobacter aerogenes*. Fecal coliforms are almost exclusively coliforms of fecal origin and are more specific than the coliform group. Not all (noncoliform) fecal bacteria are detected with a fecal coliforms test, and it has been demonstrated that many of the fecal coliforms are more sensitive to environmental factors, such as ultraviolet radiation (i.e., sunlight) and temperature change than many pathogens found in feces. Therefore, the absence of fecal coliform may not mean that the risk of exposure to a disease-causing organism is nonexistent. Other indicator organisms such as fecal streptococci, enterococci, and *Clostridium perfringens* have been used as indicators of water pollution, especially in situations where a specific source of pollution (e.g., cattle or human waste) is being investigated as the source of pollution. Sometimes more than one indicator organism is used to measure the risk of pathogens in a water sample. Increasingly, health regions and municipal, provincial, and federal agencies are using *E. coli* as their indicator organism of choice for surface water quality analysis. *Giadia lamblia* and *Cryptosporidium* spp. are protozoa sometimes analyzed

for in water samples. However, the procedure is more complicated and less reliable than those used for bacterial indicator organisms.

1.6 What does the presence of indicator organisms in water mean?

In itself, the presence of an indicator organism in water provides limited information. There are set maximum acceptable concentrations (MACs) for major indicator organisms in the Canadian Water Quality Guidelines. Different MACs are set for different uses of water. The MAC for *E. coli* in drinking water is below detectable limits. This typically equates to no *E. coli* found in 100 millilitres (mL) of water (about a third of a cup).[1] The guideline for recreational waters in Alberta is an average of fewer than 200 *E. coli* per 100 mL in at least five samples taken within 30 days of one another.[2] Water used for irrigation should have fewer than 100 *E. coli* per 100 mL.[3] The guidelines are set based on quantity and frequency of occurrence and the risk associated with the use of the water. The mere presence of an indicator organism or pathogen in a water sample does not mean that the water is unfit for use. A minimum number of a pathogen is required to cause an infection that may then lead to a disease (also known as an "infectious dose"), and the pathogen must enter the body through its preferred point and mechanism of entry. Standards are therefore set at levels below the minimum exposure limits in order to protect the public.

1.7 What are the sources of pathogenic organisms in Alberta streams, rivers, and dugouts?

There are many sources of contamination. These include sewage, industrial effluents, wild and domestic animals, and agricultural runoff. Surface runoff from pasture or cropland to which manure has been applied, drainage from livestock feedlots, and direct release of waste matter from livestock, wildlife, or septic systems are all potential sources of bacterial contaminants to agricultural streams and dugouts. Other sources of pollution include urban storm water runoff, animal feces, and infected bathers. Farm dugouts can have quite poor water quality, with pathogen concentrations routinely exceeding recreational water quality standards.

1.8 What are the factors that influence the survival of pathogens in surface water?

Once a water body has been contaminated with a pathogen, the survival of the pathogen in the water will be affected by the temperature, amount of nutrients, oxygen, and the presence or absence of antimicrobial agents such as salts, chlorine, and heavy metals. The temperature and nutrient load are affected by seasonality, weather conditions, and activities along the banks of a river or dugout. Principal nutrients that affect the growth of pathogenic microorganisms are sources of organic carbon, nitrogen, and phosphorous. Many of the pathogens in surface waters can metabolize simple sugars and other organic carbon, as, for example, from decaying plant and animal matter. Nitrogen may be in the forms of nitrate, nitrite, ammonia, ammonium, and organic nitrogen. It may come from runoff from agricultural operations, waste management facilities, industrial operations, and sometimes from natural activities such as nitrogen fixation in plants and lightning. Phosphorous may come from soil as well as runoff from agricultural operations, manure, and sewage. These nutrients will enhance the growth of both pathogens and nonpathogens. At higher

[1] Health Canada Guidelines for Canadian Drinking Water Quality, May 2008.
[2] Alberta Environment Surface Water Quality Guidelines for Use in Alberta, Table 3.0 Water Quality Guidelines for Recreation and Aesthetics, November 1999.
[3] Alberta Environment Surface Water Quality Guidelines for Use in Alberta, Table 2.0 Water Quality Guidelines for Agricultural Uses (CCME 1999), November 1999.

concentrations they could affect the turbidity, odour, and other aesthetic properties of the water. Pathogenic organisms thrive best at temperatures that humans prefer. In the presence of nutrients, microbial population growth increases in warm temperatures (20–40°C). Cooler temperatures (less than 10°C) either slow down or stop the growth of most pathogenic organisms (although they are not necessarily lethal), while higher temperatures (greater than 45°C) are lethal to most pathogens.

1.9 Are levels of bacteria in surface water monitored in Alberta?

Alberta Agriculture and Rural Development and Alberta Environment have ongoing surface water monitoring programs. One such project, the Alberta Environmentally Sustainable Agriculture (AESA) Water Quality Monitoring Program (AESA Stream Survey), conducted from 1997 to 2008, was designed to track changes in water quality in agricultural streams across Alberta over time. Throughout Alberta, the AESA Stream Survey monitored water quality in 23 small agricultural watersheds with different levels of farming intensity. Monitoring has been ongoing since 1995. Median fecal coliform and *E. coli* counts observed in the watersheds were typically less than 100 counts per 100 mL. For information on the historical water quality data of a river, stream, or dugout, contact the nearest Alberta Agriculture and Rural Development or Alberta Environment office.

1.10 How can we reduce the levels of pathogens and other bacteria on surface waters?

The populations of pathogens in water can be controlled. The best control is the prevention of contaminants from entering the surface waters. Alberta Agriculture and Rural Development and Alberta Environment have developed a series of best management practices aimed at reducing the levels of pathogens and other contaminants in our surface waters. This includes the restriction of livestock from direct access to streams, rivers, and dugouts; the establishment of riparian zones along water bodies; and effective treatment of municipal and domestic sewage. Cottages in close proximity to lakes and rivers should ensure that septic systems are installed by a licensed contractor (see www.aowma.com) and operated to meet the requirements of Alberta Municipal Affairs. For more information on surface water quality programs in the province, contact Alberta Environment.

2 Pathogens and Well Water

2.1 What are aquifers?

An aquifer is a geologic formation composed of saturated permeable rocks or sands or gravels capable of transmitting groundwater to wells or springs. Precipitation eventually adds water (recharges) into the porous rock of the aquifer. This means that some surface water eventually would reach an aquifer. Surface water is filtered by the soil and subsurface geology. The rate of recharge is not the same for all aquifers, though, and that must be considered when pumping water from a water well. Pumping too much water too fast draws down the water in the aquifer and eventually causes a water well to yield less and less water and even run dry. Groundwater usually travels relatively slowly. For example, in Alberta, groundwater flow of 100 m per year would be considered fast. In southern Alberta, groundwater is typically recharged by only a few millimetres of water in a year. Water pumped out of most Alberta water wells is at least decades and probably hundreds of years old.

As most rural residents who have had to drill a water well know, Alberta's groundwater resources are limited in a variety of ways. Typically rural water wells are screened in

bedrock, as there are few shallow aquifers in most parts of the province. Water wells are usually drilled to depths between 30 and 50 m (although depths can range from 5 to more than 150 m). While groundwater yields are usually sufficient for domestic and stock purposes, they are not large. For instance, they do not usually yield enough water for irrigation or industrial uses.

Groundwater quality in Alberta aquifers is often fair, typically getting poorer with depth, commonly due to high levels of dissolved salts (mainly due to elevated concentrations of naturally derived sodium and sulphate). When the concentrations of naturally derived salts increase with depth to above a certain level (typically between 200 and 350 m deep), the groundwater is no longer usable for most farm needs without treatment.

2.2 Are there naturally occurring microorganisms in the subsurface?

Microbial ecologists and researchers involved in deep subsurface investigations agree that the deep subsurface environments are not sterile. They also believe the microorganisms that live and grow there have developed unique attributes that help them survive their hostile environments. Deep subsurface organisms isolated from these environments can tolerate high pressure, low oxygen, and high temperatures in the rocks. Many of the pathogens from surface water would not be able to survive these environments. Many researchers have also established that unless an abundant supply of simple organic compounds, such as carbohydrates, is injected into the deep subsurface, surface organisms have a poor chance of survival. Near-surface microorganisms use these simple organic compounds for food to meet their growth and energy needs. In the absence of these simple organic compounds, surface microorganisms would not grow and reproduce. Microorganisms that are normal flora of the deep surface environments selectively use complex organic compounds as their energy sources. These sources include hydrocarbons and the products of chemical reactions of many metals.

One of the biggest problems that rural Albertans face with groundwater wells is the natural growth of slime around the well screen that clogs the well intake. This slime (or biofouling) is usually formed by natural bacteria that are acclimatized to living in aquifers (for example *Desulfovibrio* bacteria) and thrive around the water well screen in part because of the mixing of atmospheric oxygen into the well when it is pumped. Depending on the condition around the water well intake, sulfate-reducing bacteria (SRB) and iron-reducing bacteria (IRB) may be present. These bacteria may impart colour and odour to the water from the water well. This would not happen if bacteria were not in the subsurface. More information on biofouling can be obtained from Alberta Agriculture and Rural Development; contact information is provided at the end of the document.

2.3 What happens to pathogens if they are introduced to the subsurface?

Relatively little research has been conducted regarding the transport and persistence of pathogens in the subsurface, particularly in deep aquifers. Also, most of the research conducted to date has been on bacteria only. However, it has been found that pathogens do not generally travel large distances through fine-grained sediments (clay, silt, fine sand), but they can travel farther (with distances of 10s to 100s of metres reported and occasionally up to a kilometre) in extremely permeable material, such as in highly fractured rock, coarse sand, or gravel. These types of extremely permeable materials do not tend to occur in rural areas of Alberta, except perhaps in river-connected sand and gravel alluvial aquifers and in buried channel aquifers.

The typically low yield of Alberta farm water wells, along with the low incidence of fecal coliform counts in Alberta farm wells relative to similar surveys in Ontario, suggests that pathogens are not effectively transported through the subsurface in the depths typical of Alberta farm wells.

There has been very little study of the fate of surface microorganisms in deep aquifers, principally because it is not thought to be a common problem. The relatively low permeability at these depths (as indicated by modest water well yields), the lack of food for reproduction, and the tendency of pathogens to be filtered out or "stuck" onto subsurface material suggest that they would not survive well.

2.4 What are potential sources of pathogens to be concerned with in respect to water wells?

Sources of pathogens in well waters are similar to those of pathogens found in surface water, but can also include subsurface sources, such as on-site septic systems. Improper installation of the water well casing can allow contaminated surface water to "short-circuit" into the well intake without passing through the groundwater zone.

Most rural residences use on-site wastewater treatment systems (also known as septic systems) to distribute primary treated wastewater into the subsurface through distribution tile fields located a few tens of metres from their houses. There are required setback distances between on-site septic systems and water wells, which range from 10–100 m, depending on the type of septic system.[4] In some isolated areas of the province with extremely permeable shallow sands and gravels, this setback is apparently insufficient and wastewater effluent can reach water wells if they are located down gradient of the septic system and can therefore affect well water quality. In most areas of the province, however, it is not believed that pathogens reach well water though groundwater very often, in part because bacteria are not easily transported in the subsurface. Although difficult to prove, many groundwater scientists think pathogens reach well waters from the surface mainly through improperly constructed and/or poorly sealed water wells.

2.5 How often are pathogens found in well waters?

In general, pathogens are more prevalent in surface waters, but pathogen indicators are also found in well waters. A large survey of Ontario farms found *E. coli* and/or fecal coliform in about 20 per cent of 598 water wells sampled. Higher rates of contamination were found in shallower and older wells. Some of the water wells sampled were as shallow as 5 m, and the age of older wells was unknown.

There have been two surveys of pathogen indicators in well water in Alberta. In a study conducted in the mid-1990s, fecal coliforms were found only in about 8 per cent of 857 Alberta farmstead water wells. More than 4000 private water wells have also been sampled for the Baseline Water Well Testing Program for coalbed methane development, which has been conducted since 2006. In this case, fecal coliform or *E. coli* were found in about 4 per cent of the water wells (unpublished data, Alberta Environment). The lower rate of well water contamination in Alberta relative to Ontario is likely because Alberta water wells typically need to be drilled much deeper to find sufficient water supply. This makes them more naturally protected from pathogens that typically come from surface sources (e.g., on-site septic systems, manure piles, and dugouts).

[4] Alberta Regulation 205/98, Water Act, Water (ministerial) Regulation, Section 46.

2.6 Who sets the standards for drinking water in communities in Alberta?

Health Canada is responsible for the development of the national drinking water quality guidelines. Alberta Environment applies the Canadian Drinking Water Quality guidelines to all regulated drinking water sources in the province.

2.7 What about standards for private well water quality?

Private well water quality is the responsibility of the homeowner. Alberta Health Services recommends that homeowners submit a well water sample for bacterial and chemical analysis at minimum semi-annually. Typically, health regions will provide this service free of charge to rural residents. More specialized analyses should only need to be conducted when unusual conditions (e.g., taste, odour, illness) occur that cause concern about the water. For more specific details regarding testing frequency and procedures for your own water well, please contact your local health authority.

2.8 What can I do if I have concerns about the water quality of a well on my property?

If you have concerns about the quality of your well water from your property, contact Alberta Health Services and they will help arrange for the analysis of your water for you. Do not collect a water sample until you have received instructions on how to collect the water. Sterile water sampling containers will be supplied with detailed instructions on collection process, sample storage, and transportation. All water samples for analyses must be delivered to the lab in a cooler within specified timelines depending on the parameter to be tested for.

If your concern relates to a dugout used for agricultural purposes, you can contact Alberta Agriculture and Rural Development. Alberta Environment also provides information on water quality standards. Information on Internet resources are also at the end of this document.

3 Fate of Pathogens in Drilling Fluids

3.1 What are drilling fluids?

Drilling fluids are used in drilling operations for oil and gas wells. They are circulated down the drill string and come up again on the outside annulus carrying the "cuttings" or drilled-up subsurface rock and/or sediments. Drilling fluids provide the following five main functions: 1) cooling and lubricating the drill bit and string; 2) cleaning out the bottom of the hole beneath the drill bit; 3) stabilizing and sealing the borehole so it does not collapse and fluids are not lost; 4) controlling subsurface pressure; and 5) protecting potential hydrocarbon zones from damage.

There are three basic types of drilling fluids: water based, oil based, and gas based (e.g., air). Typically, drilling fluids for the top section of the well (also known as the surface hole) are created by using surface water (common sources include dugouts, sloughs, small creeks, and beaver dams) and allowing the natural clays from the drill cuttings to build up a more viscous fluid (also known as "mud"). Often other products, such as bentonite (or clay), polymers, and guar gum (which is a food and toothpaste additive), are added to create drilling fluids that allow for efficient, productive, and safe drilling operations. The ERCB has regulations[5] that

[5] ERCB *Directive 036: Drilling Blowout Prevention Requirements and Procedures*, Section 19.1.

prohibit the use of any potentially toxic drilling fluids when drilling above the base of groundwater protection (BGWP).[6]

Operationally, drilling fluids are designed to prevent movement of the fluids beyond the drillhole walls. In the event of lost circulation (when drilling fluid is unexpectedly "lost" into permeable areas of the subsurface), materials such as sawdust, walnut shells, and cellulose fibers are added to assist in controlling the fluid losses and to seal off any areas where losses are occurring. Drilling fluid levels are carefully monitored on the rig at all times and lost circulation issues are dealt with promptly, as proper circulation is important for safe, effective operations.

3.2 What happens to pathogens introduced into drilling fluids?

Most pathogens from surface waters would not survive well in water-based drilling fluids. The salt levels typical of drilling fluids are not tolerated well by pathogenic organisms, especially in the bacterial and cellular stages. The cyst stages of some protozoa may survive short time exposure to the mud, and a small number of bacteria species would survive in the drilling fluids, but they are unlikely to be pathogens.

3.3 Can surface water be disinfected prior to use in drilling?

Water can be pretreated or disinfected before use in drilling fluids. Chlorination of water is one of the most effective methods of disinfection. Chlorine added as bleach (sodium hypochlorite) may be added to reduce bacterial load and clarify organic levels in surface water. Drilling companies are careful with respect to the amount of disinfectants used, as too much may alter drilling mud characteristics or limit the disposal options available for the drilling fluids once drilling is complete. Certain mud systems may also require the addition of disinfectants even when nonsurface water sources are used, for example, when the drilling fluids contain guar gum. Guar gum is a carbohydrate-based mud additive used in drilling for a variety of reasons, including water loss control, viscosity control, and friction reduction. Disinfection of the water is required to prevent the bacterial breakdown of carbohydrates such as guar gum, which are used by microorganisms as a food source.

3.4 Are water wells at risk for pathogen contamination by oil and gas operations drilling with surface water?

It is unlikely that well water will be contaminated by drilling fluids made up with surface water. Pathogen transport over even small distances is highly unlikely in the subsurface except in the most permeable of sediments, which are rare in typical resource drilling environments in Alberta. Given the typically low yield of groundwater wells in rural Alberta, the short time period over which drilling is typically conducted (a few days), the relatively small infiltration distance of lost fluids from the wellbore, the inability of pathogens to survive conditions created in the drilling fluids or subsurface, and the relatively low incidence of detection of pathogen indicators in water wells, it is unlikely that pathogens would survive for significant flow distances in the subsurface.

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[6] Alberta Environment defines saline groundwater as having greater than 4000 milligrams per litre total dissolved solids. The BGWP is the depth at which saline groundwater is likely to occur. It is calculated as the base of the deepest protected (non-saline groundwater-bearing) formation plus a 15 metre buffer.

4 Contact Information

Alberta Agriculture and Rural Development
http://www.agric.gov.ab.ca/
J. G. O'Donoghue Building
203, 7000 - 113 Street
Edmonton AB T6H 5T6
Phone toll free in Alberta: 310 FARM (310-3276) or 1-866-882-7677
Out of province: 1-403-742-7901

Alberta Environment
http://www.environment.alberta.ca/
To report an environmental emergency or file a complaint, call the 24-hour Environment Hotline at 1-800-222-6514 toll free
Alberta Environment Information Centre:
1-780-427-2700 (toll free by first dialing 310-0000)
E-mail: env.infocent@gov.ab.ca

Alberta Health Services
http://www.albertahealthservices.ca/
Toll-free general inquiries: 1-866-943-1120
Alberta Health Services Corporate Office
700 Manulife Place
10180 - 101 Street
Edmonton AB T5J 3S4
Phone: 780-342-2000
Fax: 780-342-2060

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Customer Contact Centre
640, 5 Avenue SW
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Phone: 403-297-8311
Fax: 403-297-7336
E-mail: Inquiries@ercb.ca

Farmers' Advocate Office (FOA)
305, 7000 – 113 Street
Edmonton AB T6H 5T6
Phone: 403-310-FARM (3276)
Fax: 780-427-3913
E-mail: farmers.advocate@gov.ab.ca

Health Canada
www.hc-sc.gc.ca
Alberta Region Office
Suite 710, Canada Place
9700 Jasper Avenue
Edmonton AB T5J 4C3
Phone: 780-495-6815
Fax: 780-495-5551
E-mail: info@hc-sc.ca

5 Internet Resources

Health Canada
Guidelines for Canadian Drinking Water Quality (May 2008)
Accessed at http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/sum_guide-res_recom/micro_e.html#3

What's in Your Well? A Guide to Well Water Treatment and Maintenance
Accessed at http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/well-puits_e.html

Guidelines for Recreational Water Quality
Accessed at http://www.hc-sc.gc.ca/ewh-semt/water-eau/recreat/index_e.html

Alberta Environment
Surface Water Quality Guidelines for Use in Alberta, 1999
Accessed at http://environment.gov.ab.ca/info/library/5713.pdf

Alberta Agriculture, and Rural Development
Water wells that last for generations, 1996
Accessed at http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/wwg404

Quality Farm Dugouts
Accessed at http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/All/eng4696

6 Authors

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Dr. Abimbola Abiola is the Chair of the Olds College School of Innovation, and has been an Instructor in Land Resource Management at the college for the last 14 years. He earned a Ph.D. in Microbial Ecology from the University of Regina, Regina, Saskatchewan, specializing in the microbiology of the deep subsurface. Prior to his doctorate degree, he received a B.Sc. (Soil Microbiology) and M.Sc. (Environmental Microbiology) from the University of Ife, Ile-Ife, Nigeria. His research foci are in bioremediation of contaminated environments, process optimization in biogas, biodiesel and composting systems, and environmental waste management.

Dr. Abiola is member of many professional bodies, including Alberta Institute of Agrologist (P.Ag.), Agricultural Institute of Canada, Canadian Society for Microbiology, American Society for Microbiology, and the New York Academy of Sciences. He currently serves on many provincial and national committees on agriculture, human health, and the environment.

M. Cathryn Ryan, Ph.D., P.Eng, P.Geol.

Dr. Ryan is an associate professor in the Department of Geosciences at the University of Calgary. Dr. Ryan earned her Ph.D. and M.Sc. in Earth Sciences from the University of Waterloo, Ontario, and her undergraduate degree in Geological Engineering from Queen's University, Kingston, Ontario. Her research interests focus on groundwater and surface water quality issues. She received a City of Calgary Award for "Individual Environmental Achievement" in 2008 and was awarded the "Inspired Community Excellence Award" by the University of Calgary Faculty Association in 2009.

Dr. Ryan is a member of the American Geophysical Union, Association of Professional Engineers, Geologists, Geophysicists of Alberta, Bow River Basin Council, Geological Society of America, International Association of Hydrogeologists, and National Ground Water Association.

7 Reviewed Literature

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